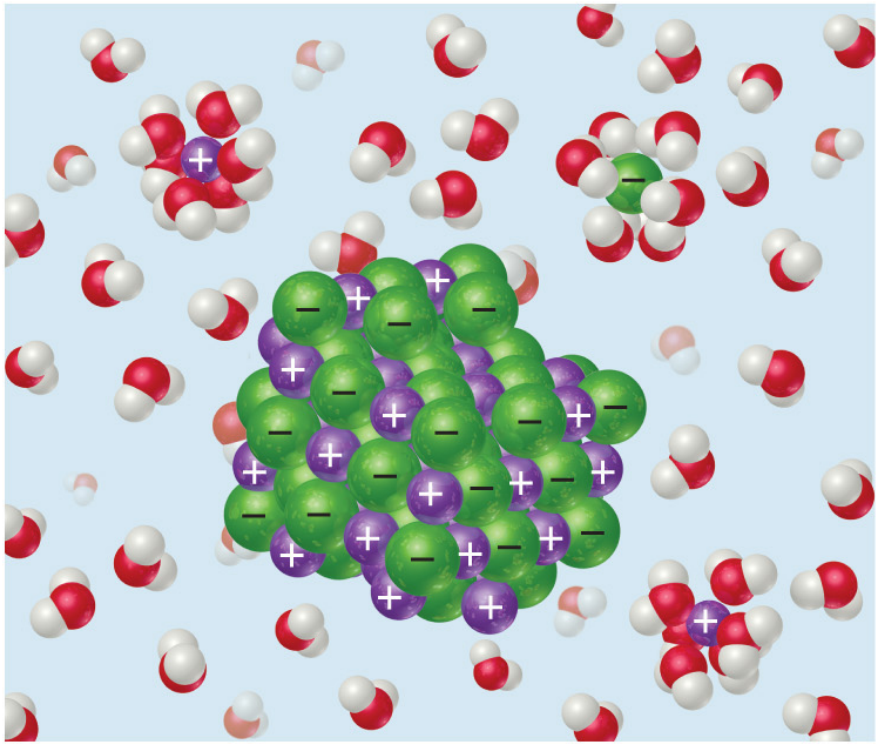
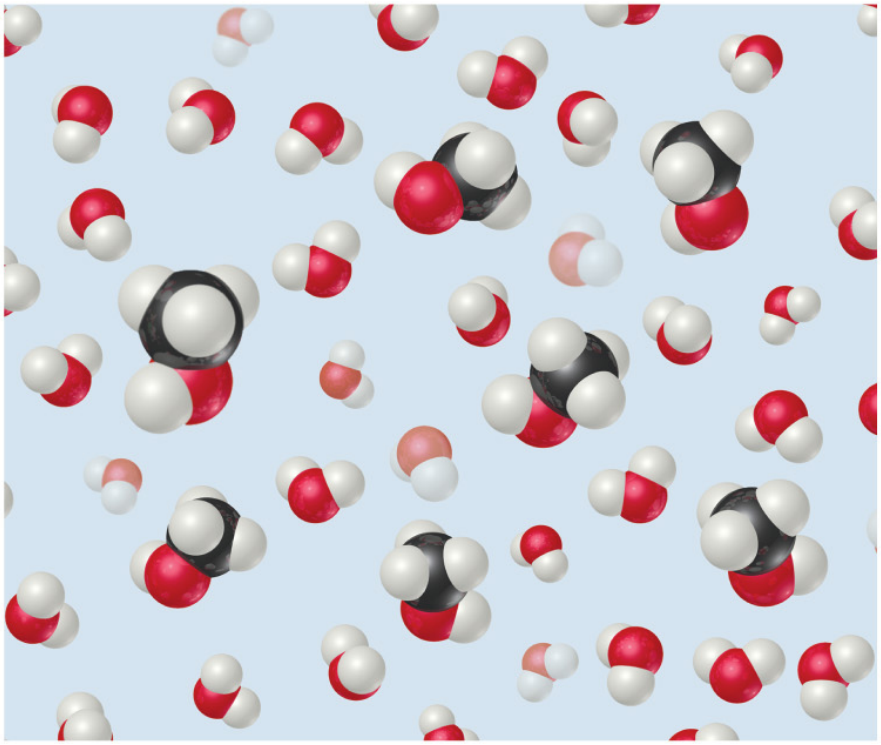
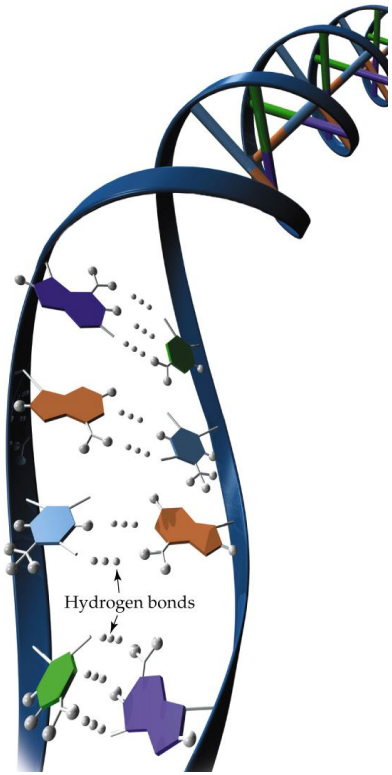
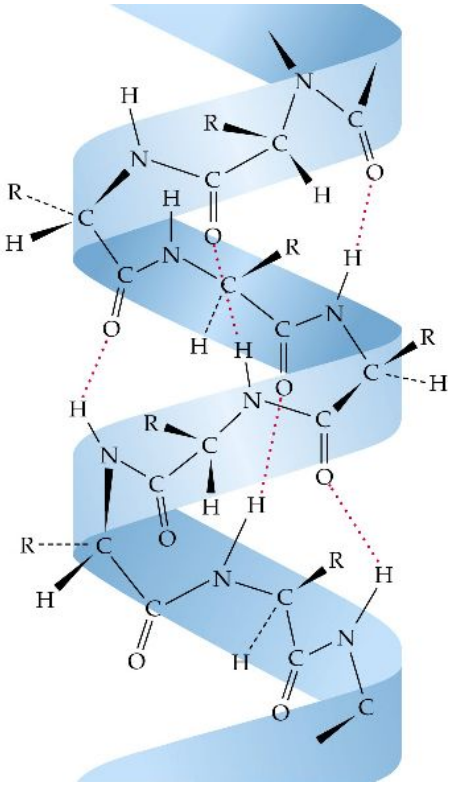
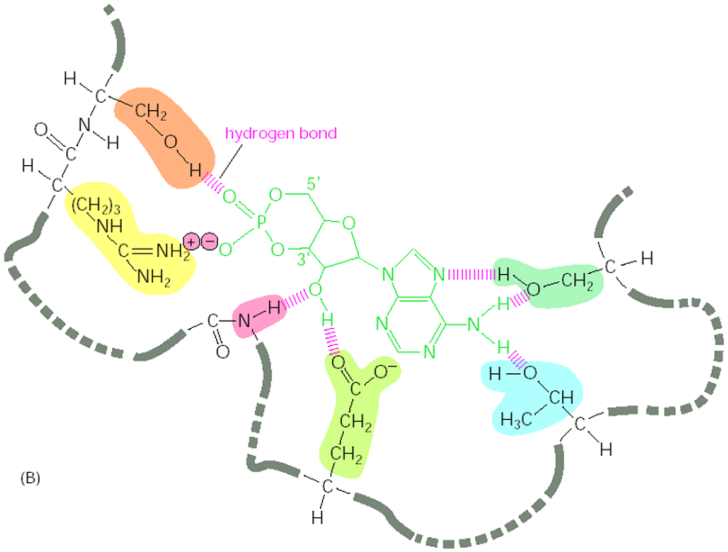
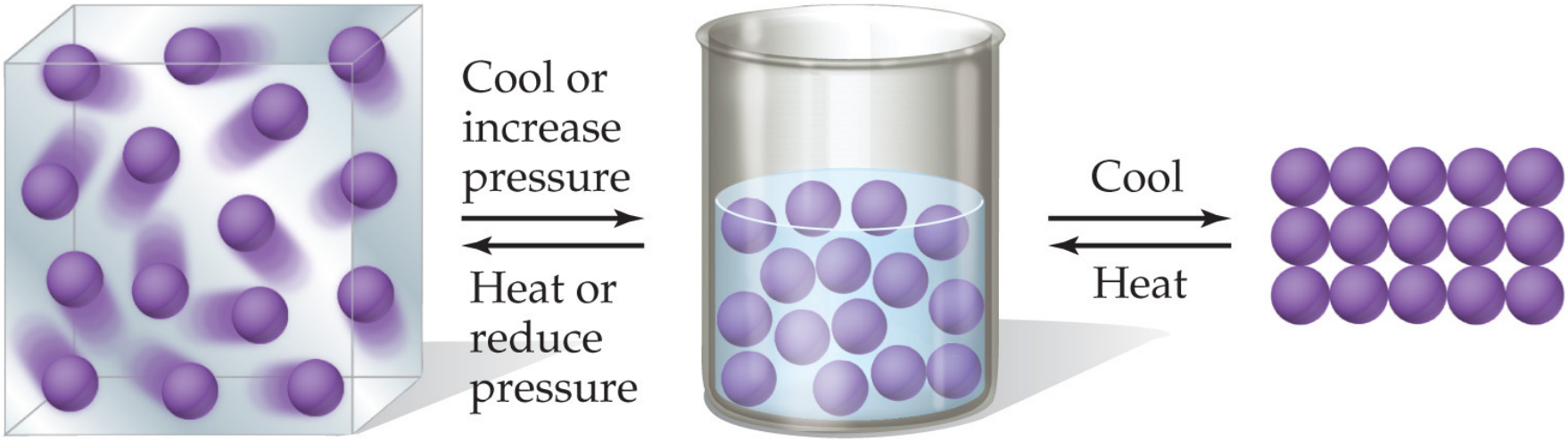





Hydrogen bonds




hydrogen bond
(B)



Gas

Total disorder; much empty space; particles have complete freedom of motion; particles far apart

Liquid

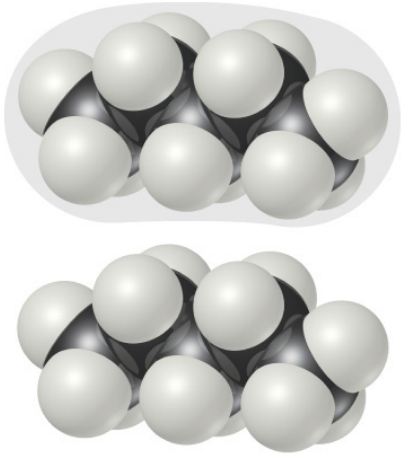
Disorder; particles or clusters of particles are free to move relative to each other; particles close together

Crystalline solid

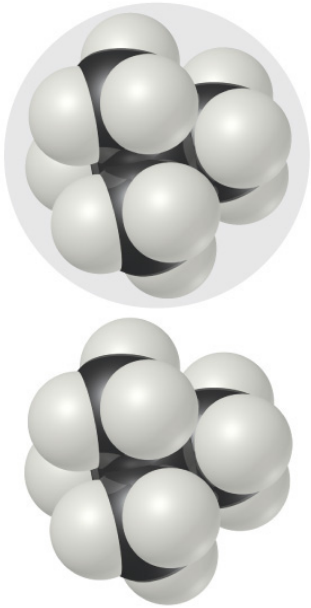
Ordered arrangement; particles are essentially in fixed positions; particles close together

TABLE 11.3 ■ Boiling Points of the Halogens and the Noble Gases

Halogen	Molecular Weight (amu)	Boiling Point (K)	Noble Gas	Molecular Weight (amu)	Boiling Point (K)
F_2	38.0	85.1	He	4.0	4.6
Cl_2	71.0	238.6	Ne	20.2	27.3
Br_2	159.8	332.0	Ar	39.9	87.5
I_2	253.8	457.6	Kr	83.8	120.9
			Xe	131.3	166.1



n-Pentane
(bp = 309.4 K)



Neopentane
(bp = 282.7 K)

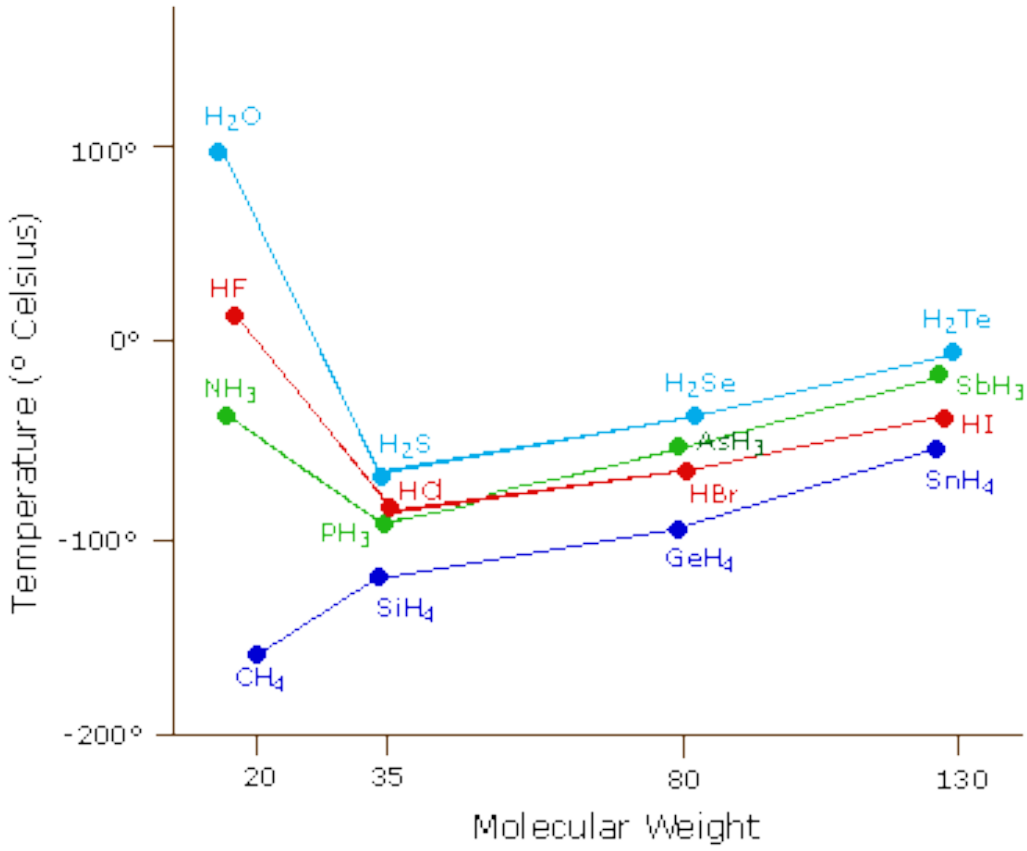
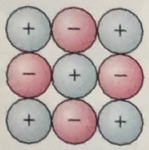
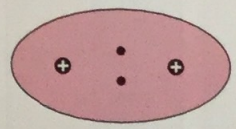
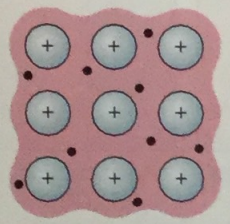
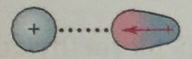
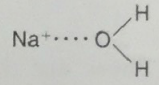
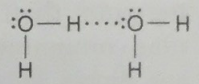
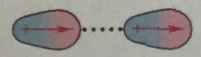
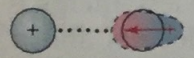
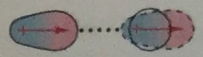
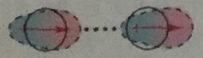
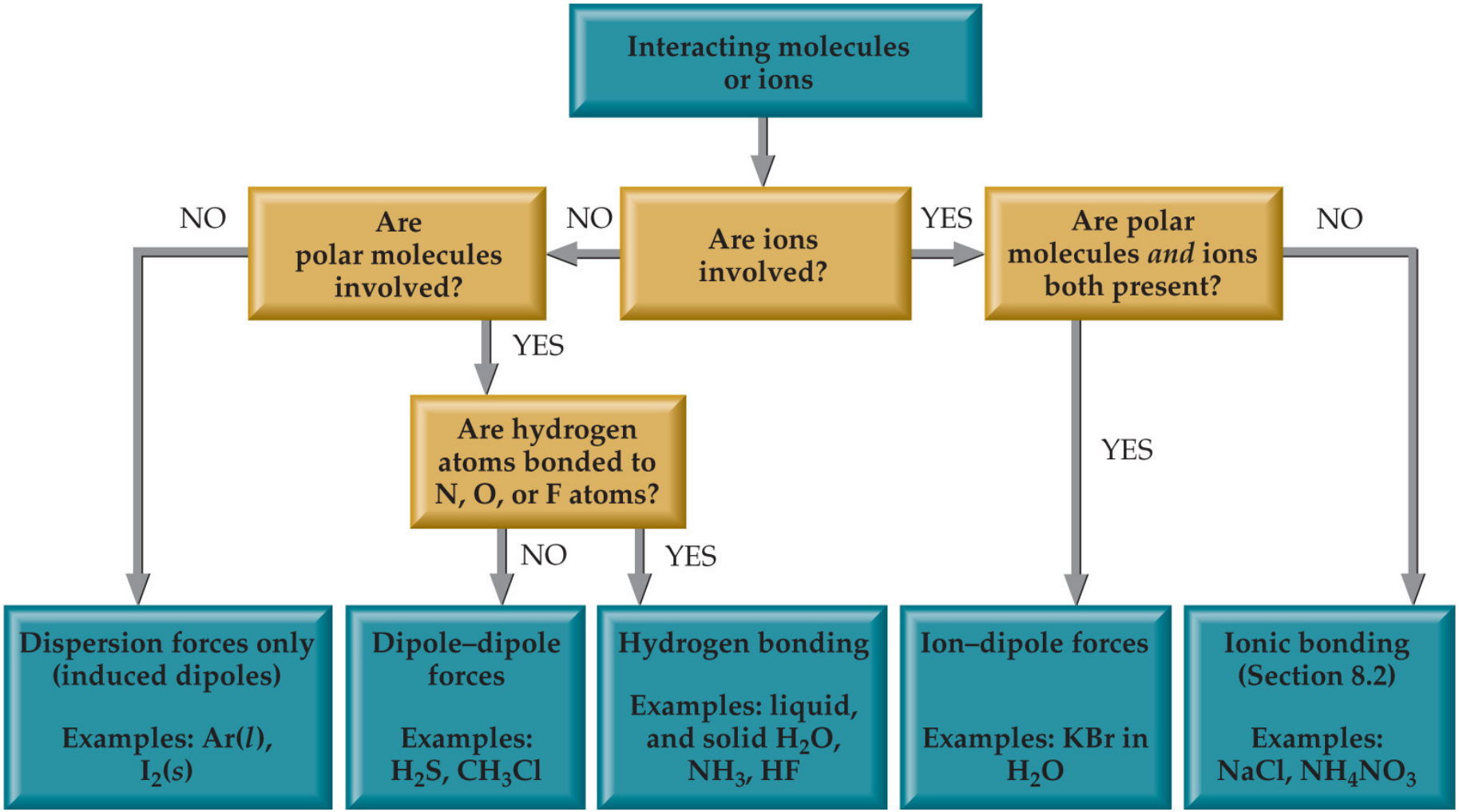

Temperature (° Celsius)
100°
0°
-100°
-200°
20
35
80
130
Molecular Weight
H2O
HF
NH3
H2S
HCl
PH3
CH4
SiH4
H2Se
AsH3
HBr
GeH4
H2Te
SbH3
HI
SnH4

Table 12.2 Comparison of the Energies Associated with Bonding (Intramolecular) Forces and Intermolecular Forces

Force	Model	Basis of Attraction	Energy (kJ/mol)	Example
Intramolecular				
Ionic		Cation–anion	400–4000	NaCl
Covalent		Nuclei–shared e^- pair	150–1100	H—H
Metallic		Cations–delocalized electrons	75–1000	Fe
Intermolecular				
Ion-dipole		Ion charge–dipole charge	40–600	
H bond		Polar bond to H–dipole charge (high EN of N, O, F)	10–40	
Dipole-dipole		Dipole charges	5–25	I—Cl···· I—Cl
Ion-induced dipole		Ion charge–polarizable e^- cloud	3–15	Fe^{2+}····O_2
Dipole-induced dipole		Dipole charge–polarizable e^- cloud	2–10	H—Cl···· Cl—Cl
Dispersion (London)		Polarizable e^- clouds	0.05–40	F—F···· F—F


Interacting molecules or ions
Are ions involved?
NO
Are polar molecules involved?
YES
Are polar molecules *and* ions both present?
NO
YES
Are hydrogen atoms bonded to N, O, or F atoms?
NO
YES
YES
NO
Dispersion forces only (induced dipoles)
Examples: Ar(*l*), $I_2(s)$
Dipole–dipole forces
Examples: H_2S, CH_3Cl
Hydrogen bonding
Examples: liquid, and solid H_2O, NH_3, HF
Ion–dipole forces
Examples: KBr in H_2O
Ionic bonding (Section 8.2)
Examples: NaCl, NH_4NO_3

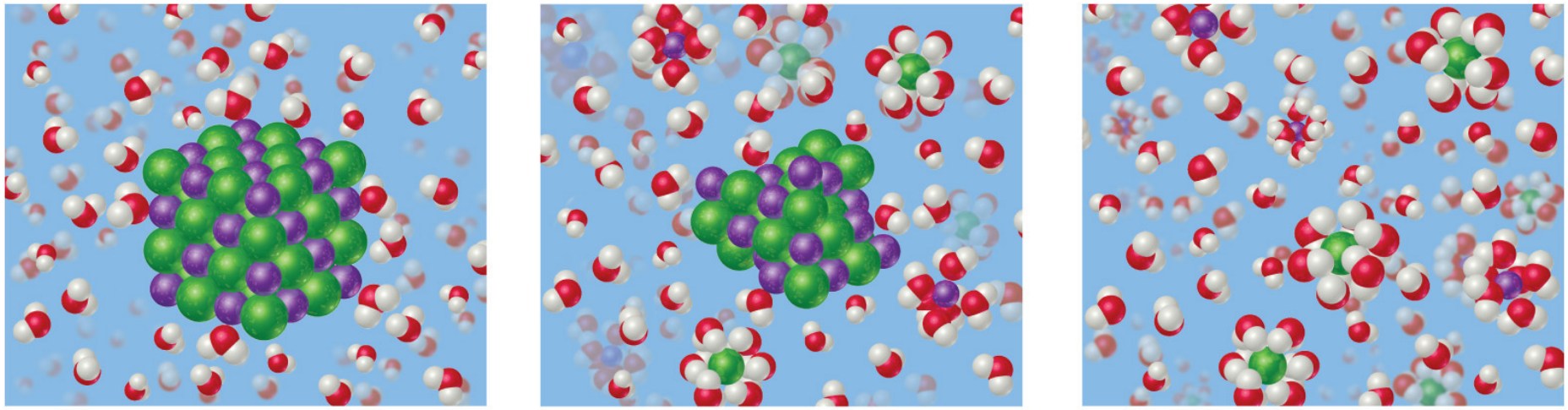
(a) Identify the intermolecular attractions present in the following substances:

CH_3CH_3, CH_3OH, and CH_3CH_2OH

(b) Which substance has the highest boiling point?

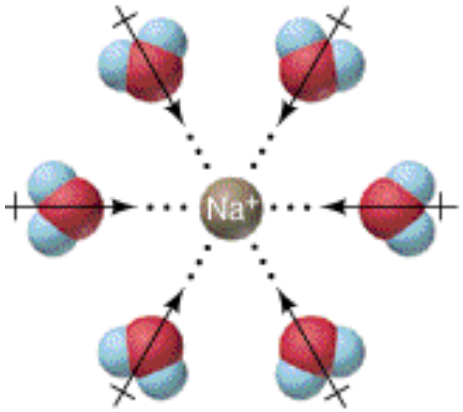
How Does a Solution Form?

As a solution forms, the solvent pulls solute particles apart and surrounds, or solvates, them.

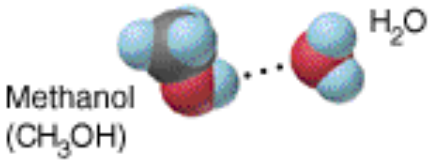


Intermolecular Forces

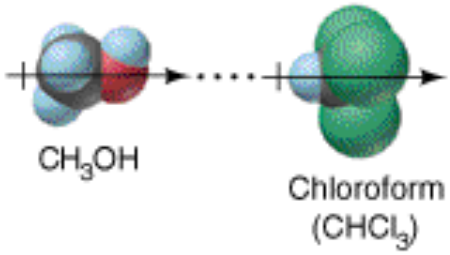
These forces may contribute to or oppose the formation of a solution.



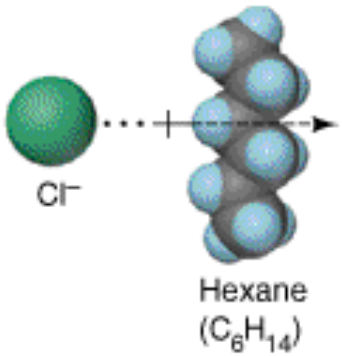
Ion-dipole



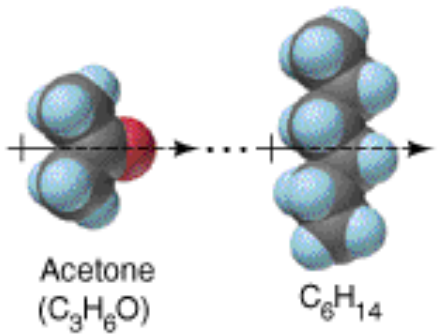
H bond



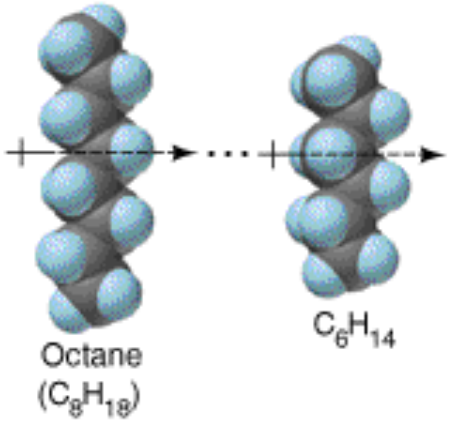
Dipole-dipole



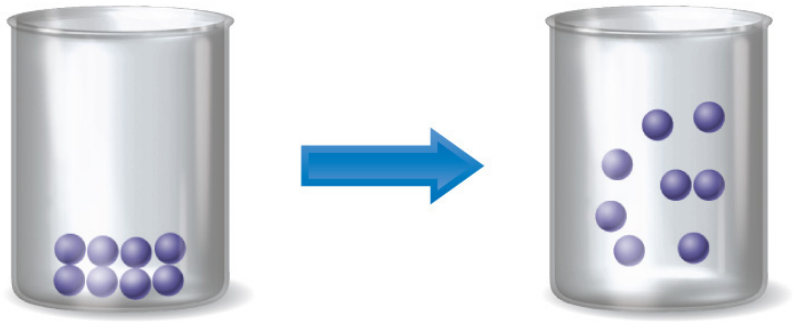
Ion-induced dipole



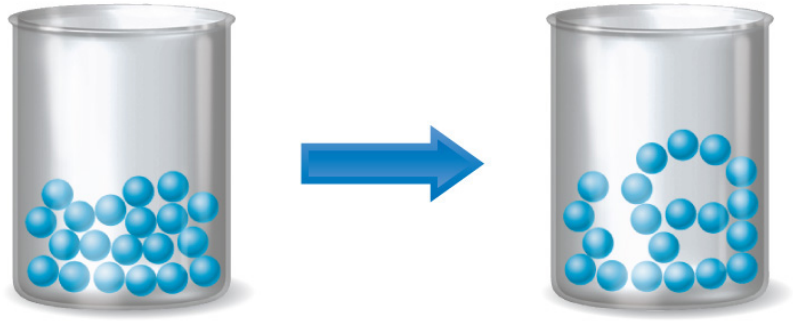
Dipole-induced dipole



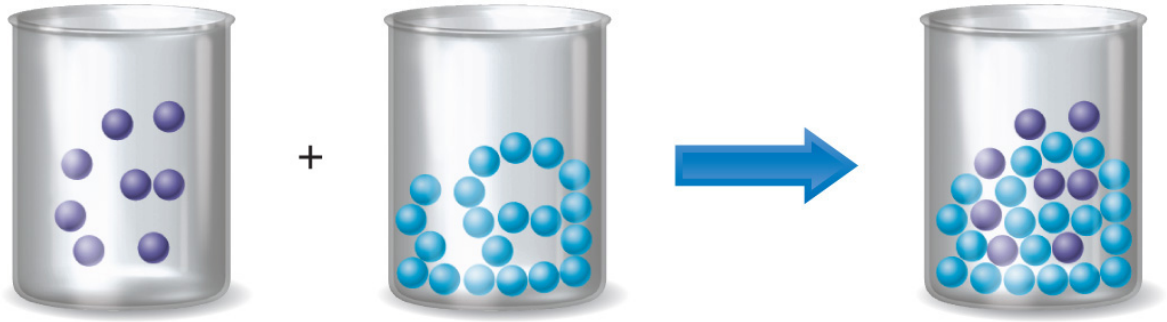
Dispersion



ΔH_1: Separation of solute molecules

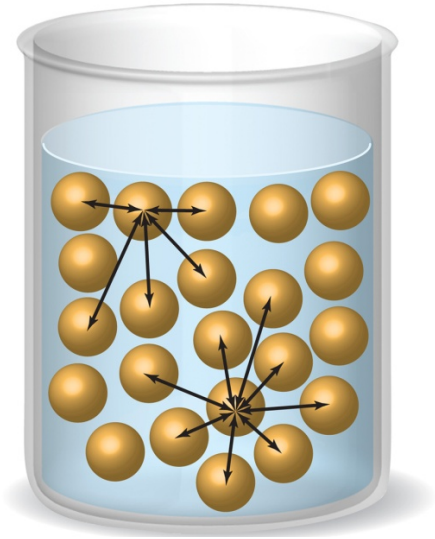


ΔH_2: Separation of solvent molecules



ΔH_3: Formation of solute–solvent interactions

Surface Tension



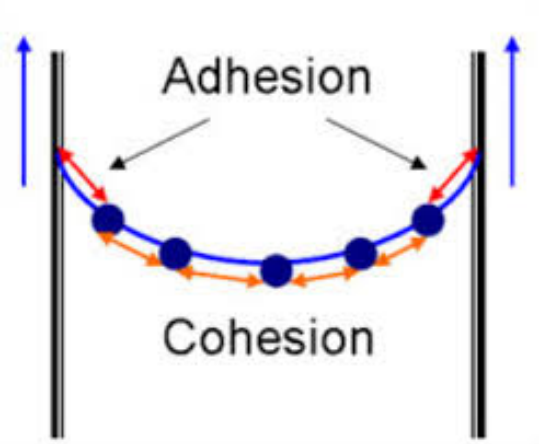
Surface tension results from the net inward force experienced by the molecules on the surface of a liquid.

Viscosity

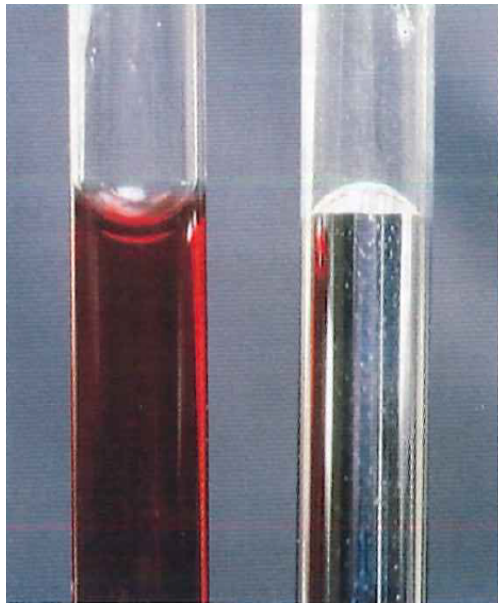
- Resistance of a liquid to flow is called viscosity.
- It is related to the ease with which molecules can move past each other.
- Viscosity increases with stronger intermolecular forces and molecular shape.
- Viscosity decreases with higher temperature.

Capillary Action

Ability of a liquid to flow against gravity up a narrow tube.

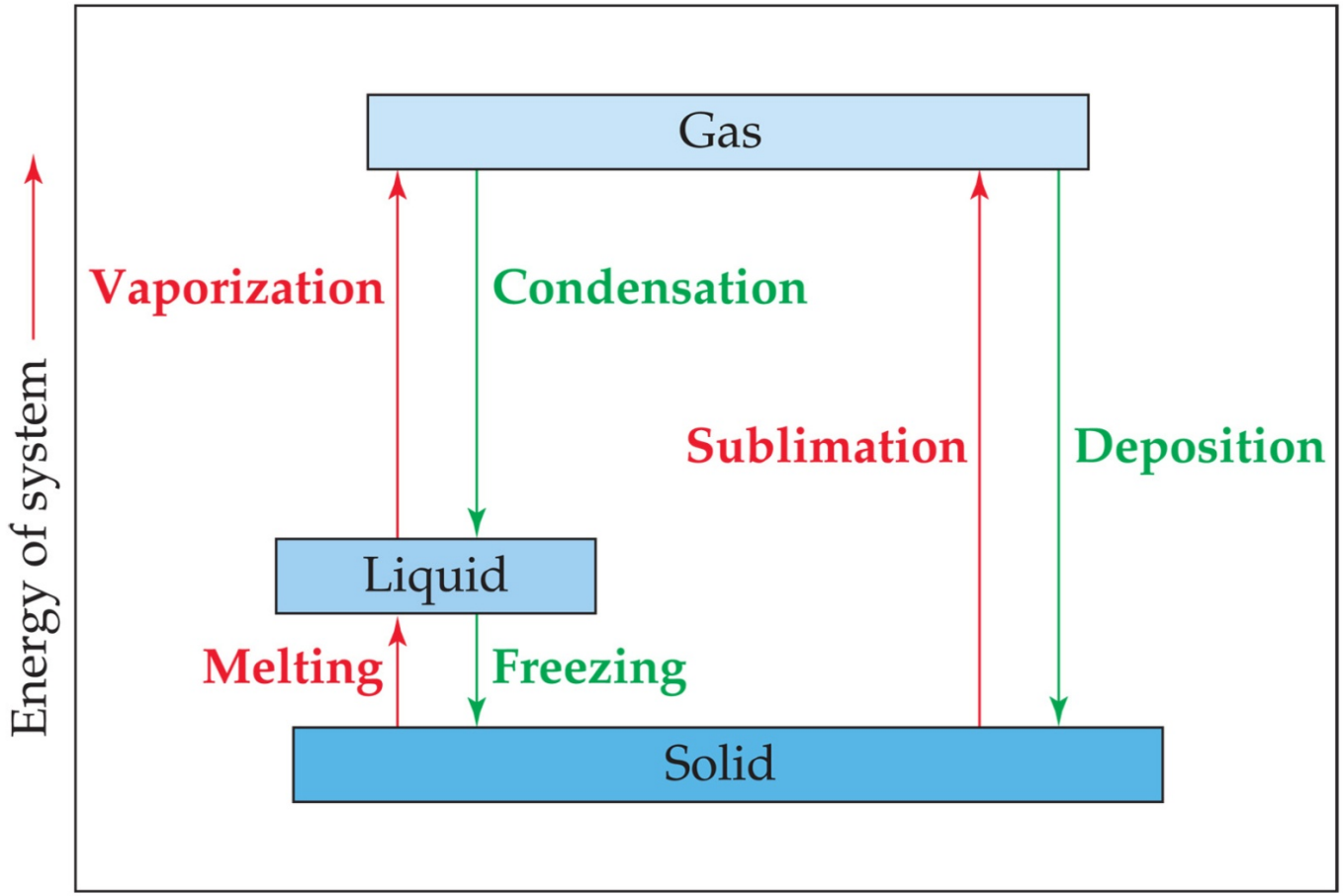


HCl

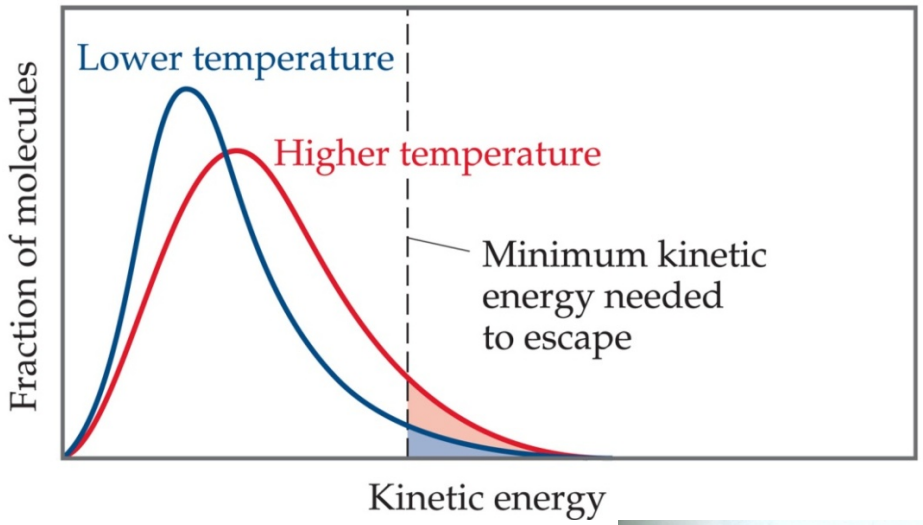


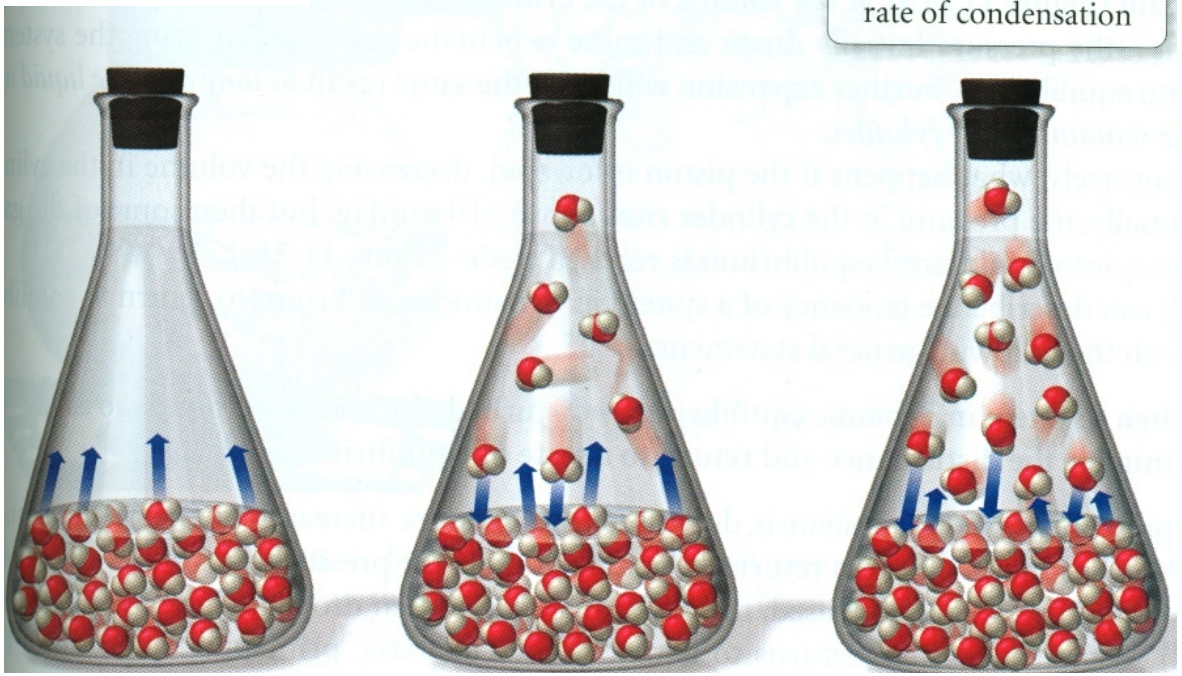
Water Mercury

Phase Changes



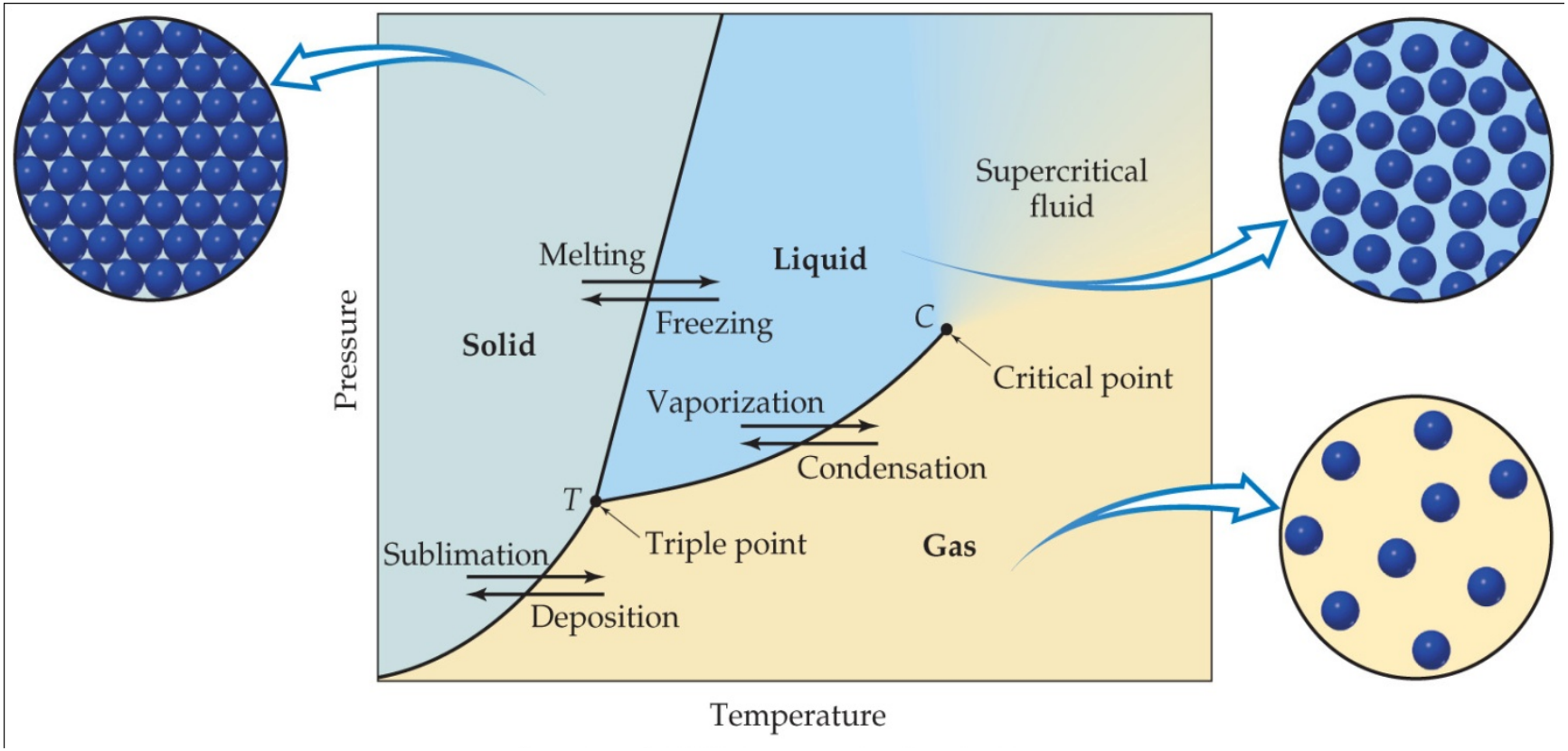
Dynamic Equilibrium

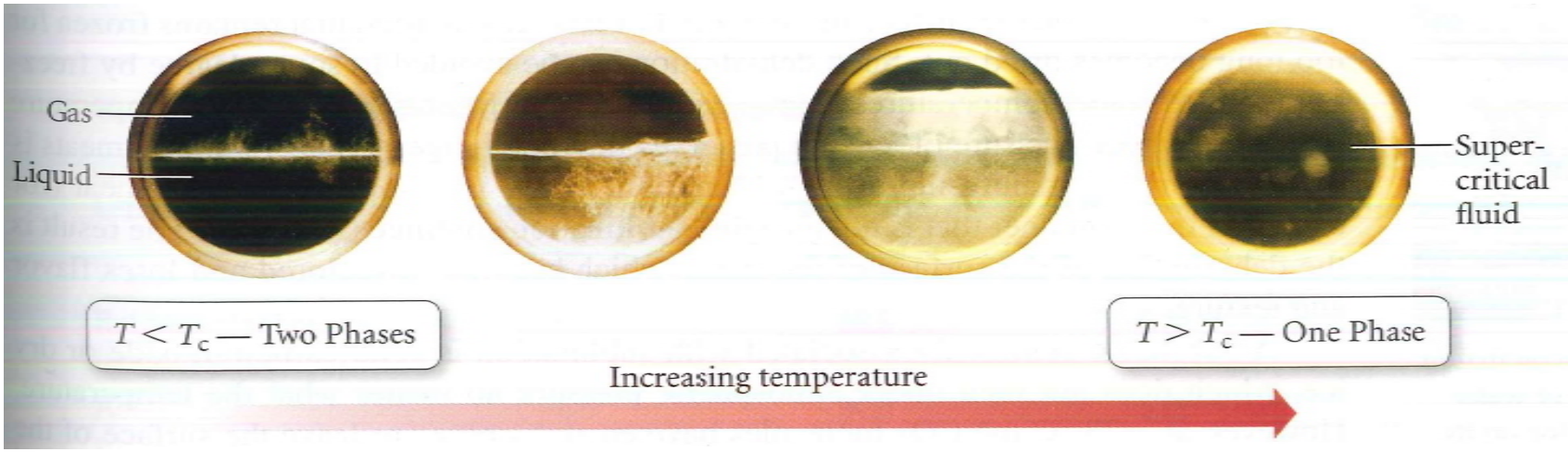




Phase Diagrams

Phase diagrams display the state of a substance at various pressures and temperatures and the places where equilibria exist between phases.




Gas
Liquid
Super-
critical
fluid
$T < T_c$ — Two Phases
$T > T_c$ — One Phase
Increasing temperature